



# Deep moonquakes reveal thickness of the lunar crust

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Charlotte Rowe of the Laboratory's Geophysics group and collaborators from the Delft University of Technology in the Netherlands have reported the first use of the seismic interferometry technique applied to study the internal structure of the Moon. The *Journal of Geophysical Research: Planets* published the [research](#) and featured it as an [Editor's Highlight](#).

During the NASA Apollo missions, astronauts installed seismometers on the near side of the Moon to record moonquakes. The instruments transmitted continuous seismic data to the Earth between July 1969 and September 1977. Early analysis identified four types of natural moonquakes: meteoroid impacts, thermal moonquakes, shallow moonquakes, and deep moonquakes.

## Significance of the work

Rowe and collaborators applied body-wave seismic interferometry to the data to study clusters of deep moonquakes (hypocenters at depths between 700 and 1200 km). Seismic interferometry creates new seismic responses by cross-correlating seismic observations from multiple, nearly co-located sources, at each of several different receiver locations. Use of data that the Apollo stations collected from naturally occurring moonquakes obviates the need for active seismic sources, such as explosives and artificial impacts, for the research.

Seismic interferometry has been applied previously to study the internal structure of the Earth. This was the first time that the technique has been applied to investigate deep moonquakes to examine the Moon's internal structure.

The team identified the lunar seismic Moho (Mohorovičić discontinuity, the boundary between the crust and the mantle). The results reveal a layer at a depth of about 50 km below the Apollo seismic stations. This information provides an independent estimate of the thickness of the lunar crust. Knowledge of the crustal thickness is important for understanding the genesis and history of the Moon. It has implications for bulk composition, the origin of Moon rocks, and other aspects of lunar evolution. The authors suggest that deep moonquake seismic interferometry could be extended to imaging the subsurface below seismic stations on the far side of the Moon if future missions install them.

## Achievements

The researchers were the first to use body-wave seismic interferometry to study deep moonquakes. The team applied seismic interferometry to P wave codas of deep moonquakes recorded by the Apollo seismic stations to retrieve a reflection image of the Moon's subsurface. The P-wave coda is the extended function, following the P-wave arrival, of oscillations generated by reverberations and scattering off of structural heterogeneities at depth. The investigators analyzed the P wave coda of seven clusters of deep moonquakes whose incoming wavefronts of the direct P wave phases are approximately planar at the stations, and whose ray parameters are sufficiently small. The results of this study reveal a laterally coherent acoustic boundary at a depth of about 50 km below the Apollo seismic stations, which the researchers interpreted as the lunar seismic Moho. The information provides an independent estimate of the thickness of the lunar crust.

## The research team

Authors of the publication include Rowe and Yohei Nishitsuji, Kees Wapenaar and Deyan Draganov of Delft University of Technology.

NNSA sponsored the Los Alamos portion of the research. Capabilities developed and used in this analysis support the Laboratory's Global Security mission area and the Science of Signatures science pillar through the ability to investigate earth structure and determine the location and magnitude of earthquakes and underground explosions. In the photo below, Astronaut Buzz Aldrin installs a seismometer on the Moon. Photo credit: NASA.

The second image is a schematic of deep moonquake seismic interferometry. (a): Deep moonquake clusters (yellow circles) closest to an Apollo station (blue triangles) are selected based on their incidence angle to the station. (b and c): Schematic raypaths of various types of P reverberations between high-impedance structural layers. (d and e): Cartoon of retrieved zero-offset plane wave from autocorrelation of hypothetical paths in (b) and (c) respectively.

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[www.lanl.gov](http://www.lanl.gov)

**(505) 667-7000**

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